Palaeogeographic analysis of the Dutch part of the Roman limes and its hinterland

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Summary in English

Chapter 1: Introduction

The primary aim of this study as part of the larger 'Finding the limits of the *limes*' project is to analyse and reconstruct the cultural landscape of the Dutch *limes* area, more specifically looking at the site and settlement patterns, the transport networks and their interrelationship with the natural environment.

Firstly, in order to understand spatial developments and patterns in the cultural landscape in relation to the natural landscape, the natural landscape must be accurately known first. Since the current project focusses on both the Cananefatian as well as the Batavian *civitates*, the first main aim is to extend the existing reconstructions of the natural landscape to cover the entire Dutch *limes* area. From a more methodological standpoint however, a concern is that there are implicit and sometimes explicit uncertainties in every palaeogeographic reconstruction. A secondary aim is therefore to make these uncertainties clear and definable, and possibly test the influence of the uncertainty on further analysis.

A second main aim of this thesis is a reconstruction and analysis of transport networks that were active in the region. Elaborating on that, the first aim here is to quantify and make explicit the factors that govern transportation, in terms of agents, frequency, goals and modes of transport, as well as the role of the natural environment promoting or hindering transport. The results can be used for transport network reconstruction. The application of network analysis on such modelled transport networks potentially allows us to infer information about archaeological questions such as the hierarchy in settlements and the role of certain individual sites (both settlements and Roman military sites) in the network, which can be tested against archaeological evidence.

The third main aim of this thesis involves an analysis of individual sites within the landscape. Knowing the landscape position of a site can inform us about the potential governing factors of site location decisions. To achieve this, sites are firstly analysed looking at individual factors and secondly through a multivariate analytical approach, looking at all possible governing factors simultaneously, from which information can be inferred on the relative importance of individual factors, the relationship between individual factors or the amount of variation in the site distribution that is explained by the factors under consideration.

Chapter 2: Natural palaeogeography

This chapter presents the work done on the natural palaeogeography of the Dutch part of the Roman *limes* within the 'Finding the limits of the *limes*' research project. At the start of the project, a reconstruction of the natural palaeogeography of the Dutch *limes* area, suitable for detailed quantitative analyses, was not yet available. The only palaeogeographic reconstructions available for the entire research area are too coarse for such approaches. Projects with detailed palaeogeographic reconstructions have been undertaken in the past for smaller areas, examples being the project on the western Netherlands in the first millennium and the project on the Roman *limes* in the Old Rhine area. The work done in the latter project has been incorporated in this study, and the methodology for reconstruction has been applied to extend the map to cover the entire research area.

Furthermore, even though detailed palaeogeographic reconstructions were available for some regions of the Dutch *limes* area, the full analytical potential of such reconstructions is yet to be explored. The palaeogeographic map of the Dutch *limes* area during the Roman Period is constructed with the intention of using it for spatial analysis, including path modelling, network construction, site location analysis and agricultural production models.

An addition that was added to this work that was underappreciated so far in palaeogeographic research is the explicit acknowledgement of uncertainty. In the palaeogeographic reconstruction of the Dutch *limes* area in this project, it is aimed to make uncertainty more explicit by building uncertainty maps and including the various sources of uncertainty. When considering the use of palaeogeographic maps for spatial analyses and modelling it is important to know where uncertainty resides, as they can influence the outcome of the research.

Chapter 3: The archaeological site dataset

One of the most vital components for a regional study is a reliable archaeological site dataset upon which the analyses and interpretations can be based. This chapter presents the archaeological site database used in this study.

Most archaeological information in the Netherlands is registered in the national archaeological database ARCHIS, where it is stored at the level of individual observations (essentially equivalent to findspots). To arrive at an archaeological site, an interpretation thus has to be made of the observation data. One observation or multiple observations together form one site in this study according to predefined criteria. The first of these criteria is the number of finds in observations that are within a defined spatial range, set here at 10. The second criterion for defining a site is that spatial range in which observations are made, set here at a radius of 250 m. After defining an observation or a number of observations as an archaeological site, the next step is to assign an interpretation regarding the nature of that site. In general, the site classification in this project follows the structure established in the preceding studies of the Dutch part of the Roman *limes*. Settlements are subdivided between military settlements (further subdivided into *castra*, military camps, *castella*, watchtowers and undefined military settlements) and non-military settlements (further subdivided into larger civil settlements, stone-built rural settlements and regular rural settlements).

Although some sites (for example the excavated Roman military ones) can be dated quite precisely, the majority of sites in the database have only limited information available on which the chronology can be established. Rather than using exact time spans, the sites were dated according to the archaeological time periods used in the ARCHIS database. However, with this methodology the dating quality and precision can vary greatly over the dataset, potentially affecting any further analyses. The chronological information associated with the observations in the ARCHIS database is therefore used to reinterpret the dating of archaeological sites. For this, a Monte Carlo-simulation approach is applied wherein the number of finds in a period is calculated per run based on probabilities of existence. Based on the principle that a site is assumed to have existed when at least 10 finds were present on that location, the probability of site existence can then be given per time period on the basis of the number of runs with 10 or more co-existing finds. These values can be used in further (spatial) analyses, as a site dataset can be constructed that is based on probabilities of presence during a certain time period, rather than the original chronological information of varying quality and precision.

Chapter 4: Characterising transport systems in the Dutch part of the Roman *limes*

One of the aims of this study is to reconstruct and analyse transport networks that were active in the region, in the first place by identifying and quantifying the factors that govern movement in general as well as the movement of goods in particular. This chapter deals with the characterisation of transport, particularly for the Dutch part of the Roman *limes*.

Transport is the subset of movement or mobility where people, animals, goods or information are transported from one location to the other. Firstly, an important distinction has to be made based on the aspect of the scale of transport movements. Three interconnected networks can be recognised: an imperial exchange network, interprovincial exchange networks and regionally centred, provincial exchange networks. The latter can be further subdivided into interregional networks, regional networks and local networks. The primary interest of this study is on transport within the research area, and particularly concerning transport between the local and the military population. The first level here pertains interregional transport, meaning the movement of goods or people over larger distances (across *civitas* borders), but still within the region contained by the research area, namely the Batavian and Cananefatian *civitates*. The second level concerns regional transport, i.e. transport within a *civitas*. The lowest scale level of transport concerns the transport over relatively short distances, i.e. local scale transport. An example is the transport of goods from settlements to local markets, the majority of which likely concerned agricultural surplus production.

The purpose of transport can vary. Ones that can immediately be thought of are transport through economic market forces, social interaction, political representation or military action. Economic transport, which generally concerns the transport of commodities between production, market and consumption sites, may be the most frequently studied and most quantifiable aspect of transport. A large part of transport movements occurring in the research area must have been at least partly of an economic nature. The Roman occupation of the Dutch river area placed new demands on the local rural population, such as taxation, which could have been in the form of surplus production (or manpower for the Roman army in the Early Roman Period) or in the form of money that was raised by selling produce at local markets. The newly arising economy with unprecedented supply and demand structures must have greatly increased the number and scale of transport movements, particularly those of staple foods from production sites to markets and consumption sites.

The military population and the local population of the Rhine-Meuse delta had a multitude of transport modes available to them, each with their own specific characteristics. By no means are these modes of transport are always competitive: they may and most likely will have functioned as part of a complementary system. In this chapter a review is provided of the available literature data on the characteristics of various modes of transportation. Concerning land-based transport, in particular local transport in the Dutch *limes* area, the most common method of transport would have been foot-based travel. Animal-based transport is also available in the Dutch part of the Roman *limes*. This will primarily have involved oxen, as horses seem to not have been used as pack and certainly not as draught animals often, and mules must be imported from outside the region. Four different watercrafts are treated in the review of water-based transport, namely prams, punters, galleys and dugouts. Galleys will have had a primary function as a military craft and not much is known about punters since only one has been found in the Dutch river area. Prams are the most iconic type of water-based transport in the Dutch part of the Roman *limes*, used for the bulk transport of heavy construction materials and less heavy goods such as merchandise. In contrast, dugouts can be seen as the representative of water-based transport on more local scales.

They are the continuation of local traditions of sailing and were continuously in use even during the presence of the larger prams.

With the information presented in this chapter it has become clear that the level of understanding of transport in the Roman Period is quite good in terms of transport that is happening at supraregional scales, due to the availability of both archaeological information and written sources, as well as a long tradition of research. However, much less is known about transport on the local and regional scales, such as the interaction between the local population and the military population in the Dutch part of the Roman *limes*. For a large part this is due to the fact that transport on the these scales is not mentioned in the written sources and leaves very few archaeological traces.

Chapter 5: Modelling transport connections

Since the interest of the current study is mainly in transport on the local scale in the Dutch part of the Roman Lower Rhine *limes* (as part of the complex of scales on which transport would have occurred), we have only very few archaeological remains to work with due to the immaterial nature of local transport movements. The lack of evidence for such a common activity as movement through a landscape is not a new problem in archaeology, and computational approaches have been used for some time to study movement and patterns of movement instead. The focus of this chapter is therefore on the various aspects of modelling transport in the Dutch part of the Roman *limes* through least-cost path (LCP) analysis.

The most important decision that has to be made when modelling LCPs for walking is the establishment of the costs that will be taken into account during the analysis. Out of the many functions available to calculate costs of movement, the equation offered by Pandolf *et al.* (1977) was used as it can readily incorporate terrain coefficients and carried loads. In contrast to the widespread availability of physiological and/or experimental functions for modelling the costs of walking, much less research has been done on modelling time or energy expenditure of animal-based transport modes. Instead, a combination of formulas is used that calculate traction force over various terrains. Besides land-based transport modes, the local and military population of the Dutch part of the Roman Lower Rhine *limes* have also used water-based transport options. In this study, water-based movement with dugouts is modelled as part of multimodal paths. In general, the calculation of a LCP of a multimodal transport connection follows the same methodology as that of unimodal land-based transport connections. The only difference that is made is in the costs of movement over rivers and streams, which now accommodate water-based movement rather than form a barrier for movement.

The modelling of transport connections presented in this chapter is successful in terms of understanding the interaction between movement and the natural environment, and the realisation of that interaction in the construction of LCPs. The results show marked differences between the modelled routes of foot travel and animal-drawn carts in terms of where people move using these modes, and a further variation is introduced with the use of dugouts. However, the modelling of LCPs of foot travel could be performed with more reliability based on a stronger tradition in physiological (and archaeological) research on movement on foot, whereas animal-based and water-based transport modes had to rely on fewer and less compatible sources to the situation of the Dutch river area.

Within categories of foot travel or cart-based transport there are further differences in terms of travel time. This is important when thinking about networks of transport, where time plays a role in deciding which of the modelled transport connections are part of the network and which are not. However, despite being able to make preliminary assertions based on the modelled routes such as that the Roman military road (the primary infrastructural feature that we know of) plays no role in local-scale transport connections due to its peripheral location in this case study of the Kromme Rijn region, potential transport connections modelled through LCPs do not readily tell us anything about the functioning of transport in the Roman Period when it concerns questions such as the movement of surplus production from the rural settlements and the provisioning of the Roman military population. This requires a further interpretation and analysis, which can be performed in the context of networks of transport.

Chapter 6: Transport networks in the Dutch part of the Roman *limes*

The goal of this chapter is to study local transport networks of the Dutch part of the Roman *limes* with concepts of network science. In each section one or more problems are identified, which includes both methodological and archaeological questions, and an approach was sought to address these problems.

Firstly, a comparison is made between various network construction techniques in section 6.2, to find the network structure that is closest to the archaeological reality it aims to represent. This is a necessary step that has to be undertaken in order to move from the dataset of potential transport connections modelled through a least-cost path approach to a network that can be analysed with concepts from network science. By setting some evaluation criteria that are archaeologically relevant, such as how easy it is to move goods from rural settlements to the *castella*, measurable through the average path length, a quantitative evaluation can be made of various network construction techniques. In this case the Gabriel graph is found to be the best network structure representation of a local transport network for the distribution of goods from the local to the military population, but similarly important, this section demonstrates an approach in which such a methodological problem can be suitably addressed with the archaeological reality in mind.

The application of network analysis techniques on archaeological networks also give rise to questions of uncertainty: how dependent are the results for instance on the completeness of the dataset? In section 6.3 the effects of uncertainty on network analysis results is investigated, by constructing a model that iteratively builds networks from the existing datasets so that the dependency of network measures on the completeness of the network structure could be evaluated. It is found that 64% of the sites have a robust measurement, meaning that the results are not dependent on that specific network structure but remain the same when for instance sites are missing from or are falsely present in the dataset. On the other hand, 36% is thus not that reliable, and this must be kept in mind when applying network analysis on archaeological datasets. An important aspect of this study is that it presented a methodology through which such a question of uncertainty with the archaeological datasets in mind can be addressed.

Section 6.4 focusses on the application of network analysis on the modelled transport networks. The first case study tests an archaeological hypothesis that posits that the (re)distribution of goods in the Dutch part of the Roman *limes* was achieved through a hierarchic dendritic system, where intermediary sites functioned in between the military population in the *castella* and the local population in the rural settlements. This hypothesis is tested by contrasting two hypotheses: a null hypothesis in which all surplus produced goods flow directly to the *castella*, and the alternative hypothesis in which goods were gathered first at predetermined intermediary sites before moving to the *castella* in bulk. The network measure of path length (which equates travel time in our study) is used to evaluate these hypotheses, and it was found that in most cases distribution through the intermediary site is more efficient than a direct distribution, making the alternative hypothesis that was posited by previous archaeological studies more likely than our null hypothesis, although there is also room for a dual system in which both methods of distribution of goods co-existed. This study is a good showcase of how an archaeological idea can be tested and thus given more weight by expressing the problem in more explicit hypotheses that can be evaluated using concepts of network science.

The second case study in section 6.4 studies the role of stone-built rural settlements in a bit more depth. More particularly, the question is asked if these stone-built rural settlements had a potential control over transport movements in the network that may have led them to becoming more important over time, a property that can be evaluated using the network measure of betweenness centrality. It is found that a number of stone-built rural settlements have a higher betweenness centrality than the average settlement in their neighbourhood, and this number is greater than would be expected on the basis of the ratio of rural settlements that are stone-built. Interestingly, in most instances this is already the case in the Late Iron Age or Early Roman Period, i.e. the pre-stone-built phase of these settlements. This could thus indicate that part of the reason that these sites have become important and ultimately have become stone-built is that they have a potential to control transport movements over the network. This study is a good showcase of how network measures can be used to study the role that individual settlements have played in transport networks.

In section 6.7 the reinterpreted chronological information following the methodology presented in Chapter 3 is used explicitly to test continuity and change in transport networks through time. It is found that the application of this new chronological information does not significantly change the resulting network structures compared to the original chronology, which is an important conclusion because otherwise the results of any analyses would only be dependent on the chronological methodology applied. Instead, the reinterpreted chronology is used to study changes with more chronological reliability. This study reveals that there is a high degree of continuity in local transport networks, and this continuity is higher than would maybe be expected on the basis of continuity in the settlement dataset, indicating that local transport networks are more persistent than the settlement pattern itself. Some variations are also noticeable in the level of continuity, which can be related to known periods of instability such as the Batavian revolt and the 3rd century border collapse.

Chapter 7: Site location analysis

In this research the interest in site location has several reasons: to determine the (natural, cultural/social or historical) governing factors of settlement location choices, to investigate settlement pattern development through time, and to serve as input data for models of agricultural production. The analyses presented in this chapter consist firstly of an analysis of the individual factors (including the natural palaeogeography, rivers and streams, forts, transport networks, potential intermediary sites in transport networks, and the influence of the historical landscape), and secondly a multivariate approach in order to study the relative importance of factors and how that possibly changes through time. The latter analysis uses a Monte Carlo method approach to develop a logistic regression model for the prediction of site presence and absence in each time period.

It is found that the historical landscape and the distance to the transport network were important factors for settlement location, showing that the inclusion of cultural/social factors such as the historical landscape as well as modelled transport networks has a valuable impact on such a settlement location study. In terms of results, some interesting shifts are found in settlement location preferences through time, with a shift towards more ‘marginal’ areas in the ERP A-ERP B and MRP A-MRP B intervals, in terms of both the natural environment as well as the settlement landscape. This may for example be explained as the result of changing modes of production or as a result of increasing pressure in the core habitation area on the levees. The opposite is seen in the LRP A-LRP B shift, where new settlements were primarily located within the core habitation area rather than along the margins, perhaps because the relatively low population density did not necessitate such a move.

Chapter 8: Synthesis / Chapter 9: Conclusion

These chapters present the general results of this part of the 'Finding the limits of the *limes*' project, and place it in the wider research context. They aim to summarise and showcase some of the innovative aspects of the study, either from technical, methodological or interpretative viewpoints. To do this, Chapter 8 utilises some case studies presented in this study in the realm of transport networks and settlement location in the Dutch part of the Roman *limes*. Formulated in a more general question, the goal of Chapter 8 is as follows: what has this spatial analytical study of the cultural landscape of the Dutch *limes* area contributed to the research field of computational archaeology and related fields, and what has it contributed to the archaeological understanding of the Dutch part of the Roman *limes*?

The LCP modelling, network studies and settlement location analysis presented in this study have provided some new and valuable insights into the properties of movement on the local scale in the Dutch Rhine-Meuse delta, the potential functioning of the Roman military provisioning system, the role of individual sites within these local transport networks, and the relation between settlements and their natural and social environment. For example, the case studies applied on the modelled transport networks fin that at least for the eastern and central parts of the study area it is more likely that transport from the local to the military population was carried out through intermediary sites rather than through the forts, supporting the archaeological hypothesis of a dendritic hierarchic settlement system. Furthermore, the role that individual settlements have in these networks of transport could have given rise to the higher-status stone-built settlements, as some of these have been shown to be valuable as potential intermediary sites and/or to be centrally located on routes between other settlements. The settlement location analysis has found that settlements tend to concentrate on the levees in areas where settlements already existed previously and close proximity to transport networks. Other factor were less important, showing that the location of new settlements is mostly governed by landscape suitability and the potential to interact with other rural settlements, and not particularly to interact with the military population. These findings are valuable for archaeologists to further their thought on interactions between the local and military population of the Dutch *limes* area.

Of similar importance are the methods through which these results are achieved. By formulating the archaeological questions in such a way that they can be addressed by the computational approaches, these studies can provide new insights that were not readily extractable from the archaeological data beforehand. More specifically tailored to the approaches applied in this research, the application of LCP analysis to model local transport connections has proven valuable, as it allows for the inclusion of the natural terrain, and this was found to have significant impacts on following analyses. The application of network analysis on problems that are specifically suitable to be addressed as networks has proven to be valuable and lead to interesting archaeological conclusions, and the results of this research thus encourages similar future problems around transport to be addressed as networks as well. Important in the application of computational approaches is the need to account for uncertainty in the data and methods, and for the validation of the results. Archaeological data is inherently uncertain and incomplete, and quantitative approaches thus remain susceptible to such data problems; this research only shows some ways in which these uncertainties can be incorporated into the research to strengthen the output.